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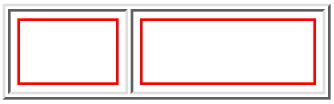

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3D Visualization of the Male Pelvis and Perineum: An Argument for Revision of Classic Representations of the Region

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Abstract

A clear understanding of the pelvic anatomy is crucial for male and female pelvic surgery as well as the fundamental mechanisms of urogenital dysfunction and its treatment. This region is conceptually difficult and is best understood when important 3D relationships are adequately represented. Conventional 2D illustrations of the pelvic region in texts and atlases are often insufficient and students of anatomy would benefit from 3D computer generated models of this region. We therefore generated 3D models of the male pelvic anatomy from the male Visible Human dataset. The models generated from these segmentations are surface-based and textured in photographic quality, fresh human tissue color, providing a uniquely realistic representation of the anatomy. Our 3D reconstructions reveal inconsistencies between the VH images and classic anatomical illustrations of this region. For example, the levator ani muscle which forms the majority of the pelvic diaphragm is classically depicted as a hammock-like structure which supports the pelvic viscera and hence the term "diaphragm". The 3D images of this structure show instead that the levator ani is considerably more cylindrical and has vertical walls that are in close apposition to the prostate. Similarly, the urinary bladder is conventionally represented as a balloon-like structure that sits directly above and on the prostate. Our images reveal that the bladder is positioned anterior to the prostate, so that the angle between the bladder neck and the prostate is more oblique than vertical. Lastly, our detailed analysis of the muscles of the perineum, particularly the muscles of the urogenital diaphragm, show their relationship to the pelvic viscera is different from the classic view.

Keywords: 3D visualizations, external genitalia, levator ani, pelvic diaphragm, pelvis, perineum, urinary bladder, prostate, Visible Human

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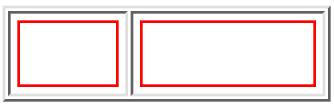

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3D Visualization of the Male Pelvis and Perineum: An Argument for Revision of Classic Representations of the Region

Introduction

The Office of Scholarly Resources at the College of Physicians and Surgeons of Columbia University is developing cross-platform electronic resources for the basic science curriculum for medical students. The Vesalius Project in particular is focusing on using the Visible Human Dataset to create interactive visualizations of anatomical structures that can be used to supplement current resources ([1]). We are creating new "curriculum-driven" resources where the segmentation of structures from the Visible Human is guided by an anatomist and designed to illustrate specific relationships and structures that the students might otherwise have difficulty conceptualizing. The structures are also chosen because they have anatomical or clinical relevance.

The anatomy of both the male and female pelvis and perineum is conceptually difficult. These regions are best understood when important 3D relationships are adequately represented. For example, in the female, the pelvic floor is frequently damaged by childbirth and an appreciation of its structure and relationships is necessary for understanding the consequences of this trauma such as incontinence and prolapse ([2]). In the male, a keen knowledge of prostatic relationships is essential for the prevention of impotence and urinary incontinence which frequently follow radical prostatectomy ([3-6]). Conventional 2D illustrations of the pelvic region in anatomical atlases and texts are often inadequate. Classical cadaveric dissections do not provide a sufficient view of the male pelvic anatomy because structures are concentrated in, and confined to, a small area and are relatively inaccessible. Dissection of this complex region can easily distort relationships and destroy landmarks. Students of anatomy would greatly benefit from 3D visualizations of the anatomical structures of the region in their correct spatial relationships. Since a clear understanding of the pelvic region is crucial for both male and female pelvic surgery as well as fundamental mechanisms of urogenital dysfunction and treatment, we have focused on this region.

Methods

We are using the Vesalius 3D Visualizer to model the 3D pelvic anatomy ([7]). The actual segmentation was performed by hand and guided by an anatomist as there is currently no reliable automated segmentation method which can separate individual muscles in the pelvis/perineum ([8]) and our goal is to extract models with all the available color texture information provided by the data. Since we stress the extraction of the detail present in the VH data, we decided not to experiment with less precise automated segmentation methods. The 3D Vesalius Visualizer reconstructs highly detailed surfaces which are rendered in the color volumetric texture provided by the Visible Human data. These initial models can be reduced, translated into standard 3D formats, and pseudo-colored, if needed. Since our models are surface-based and textured in photographic quality fresh human tissue color, we argue that this gives a uniquely realistic representation of the anatomy.

We have segmented all of the individual muscles of the pelvis and perineum and most of the pelvic viscera from the male Visible Human. We have not segmented any of the neurovascular structure nor structures from the Visible Female. Our analyses of the anatomy depicted in the resulting 3D computer reconstructions of the Visible Human and that described by others ([9]) suggest that illustrations of this region should be revised in standard texts and atlases. We discuss three areas where the computerized images we have generated provide a more accurate depiction of the pelvic anatomical structures and their relationships than standard illustrations in commonly used atlases and texts. These include: the pelvic diaphragm and levator ani muscle; the perineal muscles and their relationships; and the bladder and prostatic relationship. We will cite illustrations of these regions from a variety of texts and atlases that are available to students for study and reference and then show images from the 3D computer models and how they provide a clearer view of these structures and their relationships.

Results and Discussion

The pelvic diaphragm and levator ani

The pelvic floor is classically defined as the pelvic diaphragm which consists of the levator ani and coccygeus muscles and the fascia covering the superior and inferior aspects of these muscles ([2]). The levator ani has important functions in: supporting the abdominopelvic viscera (especially the uterus in the female);

resisting intrabdominal pressure during forced expiration, coughing, sneezing, urinating, vomiting, etc.; and in the voluntary control of urination and defecation ([2]). The pelvic diaphragm stretches between the the pubis anteriorly and the coccyx posteriorly and from one lateral pelvic wall to the other. In lateral and medial views the levator ani together with the coccygeus muscle is classically depicted as a hammock-like structure which supports the pelvic viscera and hence the term "diaphragm" (for examples see Netter [10], plates 333 & 334). The pelvic diaphragm also separates the pelvic cavity from the perineum and defines the roof of the ischioanal fossae where it arises from the lateral walls of the pelvis formed by the obturator internus muscles.

In classic depictions of the pelvic diaphragm the shape of the levator ani and its relationship to the obturator internus is difficult to discern as these muscles are often shown in different views but rarely in their entirety (see for example Netter [10] plates 333-336; Grant's ([11]) Fig. 3.19). A posterior view often shows these relationships better and also shows the pelvic diaphragm in relation to the pelvic viscera (for example, see Grant's ([11]), Fig. 3.20). Most illustrations, however, give the impression that the levator ani is a hammock or bowl-shaped structure.

Our 3D reconstructions show that the levator ani is shaped very differently than it is depicted in classic illustrations. The 3D images we have generated show instead that the levator ani is considerably more cylindrical and has vertical walls that are in close apposition to the prostate in the male ([Figures 1-4], [Movies 1-4]. In addition, we can illustrate the relationship between the levator ani and obturator internus muscles in 3D movies that more clearly illustrate the ischioanal fossae and the relation of these clinically relevant regions to the pelvic diaphragm and perineum ([Figures 5 & 6], [Movies 3 & 4]) and allow the student to add structures sequentially and build the anatomy from the "inside-out" as well as from the "outside-in" ([Movie 5]).

The perineal muscles and their relationships

Our detailed analysis of the muscles of the perineum, particularly the muscles of the urogenital diaphragm, similarly show that their relationship to the pelvic viscera is different from the classic view. The urogenital triangle contains small muscles and the erectile tissue that form the root of the penis (for example, see Netter [10], plates 355-357). The structures are usually illustrated as layers so that

the relationships can be studied and understood in the context of different spatial compartments (for example see Grant's ([11]), Fig. 3.59). However, the relationships between these structures are difficult to discern from dissections and the classic representations. Typically the latter illustrate these structures to be "larger than life" making it difficult for students to relate the anatomy of their cadavers to that seen in atlases. By segmentating the individual structures and creating a movie that builds the anatomy through the positioning of these structures in their appropriate relationships, the students can better visualize these important relationships. These layers can be combined interactively so that students can add and or subtract them for study. In this way, students can better understand how the structures of this confined region come together and form the different, clinically relevant, spatial compartments ([Figures 7-14], [Movie 6]).

The bladder and its relationships

The urinary bladder is conventionally represented as a balloon-like structure that sits directly above and on the prostate (for examples see Netter ([10]), plates 338, 343, 358; Grant's ([11]) Fig. 3.11, 3.28; Olson([13]) Fig. 345). Our images ([Figure 15], [Movies 7 & 8]) reveal that the bladder is positioned anterior to the prostate, so that the angle between the bladder neck and the prostate is more oblique than vertical. This relationship is confirmed in photographs of the region such as illustrated in Rohan et al. ([14]). We believe our 3D representation of these relationships, particularly in Movies 7 and 8, is a more "true to life" representation of the anatomy than the illustrations in most traditional atlases and texts.

Summary and Conclusions

We have segmented all of the individual muscles of the pelvis and perineum and most of the pelvic viscera from the male Visible Human Dataset. Our analysis of the anatomy depicted in the resulting 3D computer reconstructions suggests that illustrations of this region should be revised in standard texts and atlases. For example, the levator ani muscle which forms the majority of the pelvic diaphragm is classically depicted as a hammock-like structure which supports the pelvic viscera and hence the term "diaphragm". The 3D images of this structure show instead that the levator ani is considerably more cylindrical and has lateral walls that are vertical and are in close apposition to the prostate. Similarly, the urinary bladder is conventionally represented as a balloon-like structure that sits directly

above and on the prostate. Our images reveal that the bladder is positioned anterior to the prostate, so that the angle between the bladder neck and the prostate is more oblique than vertical. Finally, our detailed analysis of the muscles of the perineum, particularly the muscles of the urogenital diaphragm, show that their relationship to the pelvic viscera is different from the classic view.

While our reconstructions of the male Visible Human pelvic anatomy are based on a sample size of one, we are confident that the view of the levator ani we have generated is a valuable representation that provides a more "realistic" view of the male pelvic anatomy and its relationships. Many of the anatomical illustrations of the pelvic diaphragm available for reference (as cited above) may be more representative of the female pelvic diaphragm so that confirmation of our visualization awaits reconstruction of this structure from the Visible Female Dataset. However, there are reports in the literature that confirm the images that we ([1]) and others ([9]) have generated from the Visible Human Dataset are representative. For example, Hugoson *et al.*, 1991 ([15] report from a study using MRI that the female levator ani has a "double-convex" course with cranial and medial convexities. Similarly, Shafik reports that the levator ani is funnel-shaped, having a transverse portion cranially and a vertical portion that forms a "vertical cuff" around the intrahiatal organs ([16]) . On occasion (for an example see Clemente ([12]), Fig. 455], atlas illustrations depict the levator ani to resemble the 3D reconstructions of the levator ani we and others ([9]) have generated. Unfortunately, these illustrations are often designed to illustrate other relationships and do not necessarily feature the levator ani and the pelvic diaphragm but focus on some other anatomical relationship. In the above cited figure, for example, the illustration depicts the venous drainage of the rectum.

Our computerized models can be used interactively to reveal relationships that are not clearly visualized by any other means. For example, in our movies , the relationships between the levator ani and the prostate ([Movies 2]) and the levator ani and the obturator internus muscles ([Movies 3-5]) can be more easily discerned than they can from static 2D images. They can be used to construct and deconstruct the pelvic anatomy in normal anatomical sequence ([Movies 5-6]) or the anatomical structures can be arbitrarily combined so that important relationships normally obscured by other structures can be more clearly discerned. Ultimately, these images can be used in programs that allow the pelvis and perineum to be dissected and rebuilt repetitively on the computer screen and thus provide an

interactive means of examining and learning the relationships between the structures of the pelvic region. The 3D reconstructed models are displayed in the 3D exact spatial relationships corresponding to their locations in the Visible Human male thus allowing the viewer to see structures in their appropriate positions relative to other structures in a way that has never before been possible. The 3D anatomical structures from the pelvic region can be browsed, flown through and explored from an arbitrary viewpoint, to illustrate relationships between individual structures which can't be explained easily in medical illustrations.

It is yet to be determined which 3D visualizations are more suitable for anatomy teaching: pseudo-colored schematic, or detailed, photographic quality 3D visualizations of the pelvic anatomical structures. We plan, in the future, to conduct a formal study by a cognitive psychologist to answer these questions. Since there is no precedence in using such (photographic quality) color visualizations to teach anatomy, we might be able to set a new standard.

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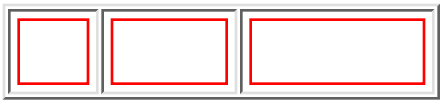

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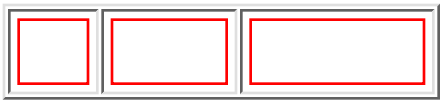

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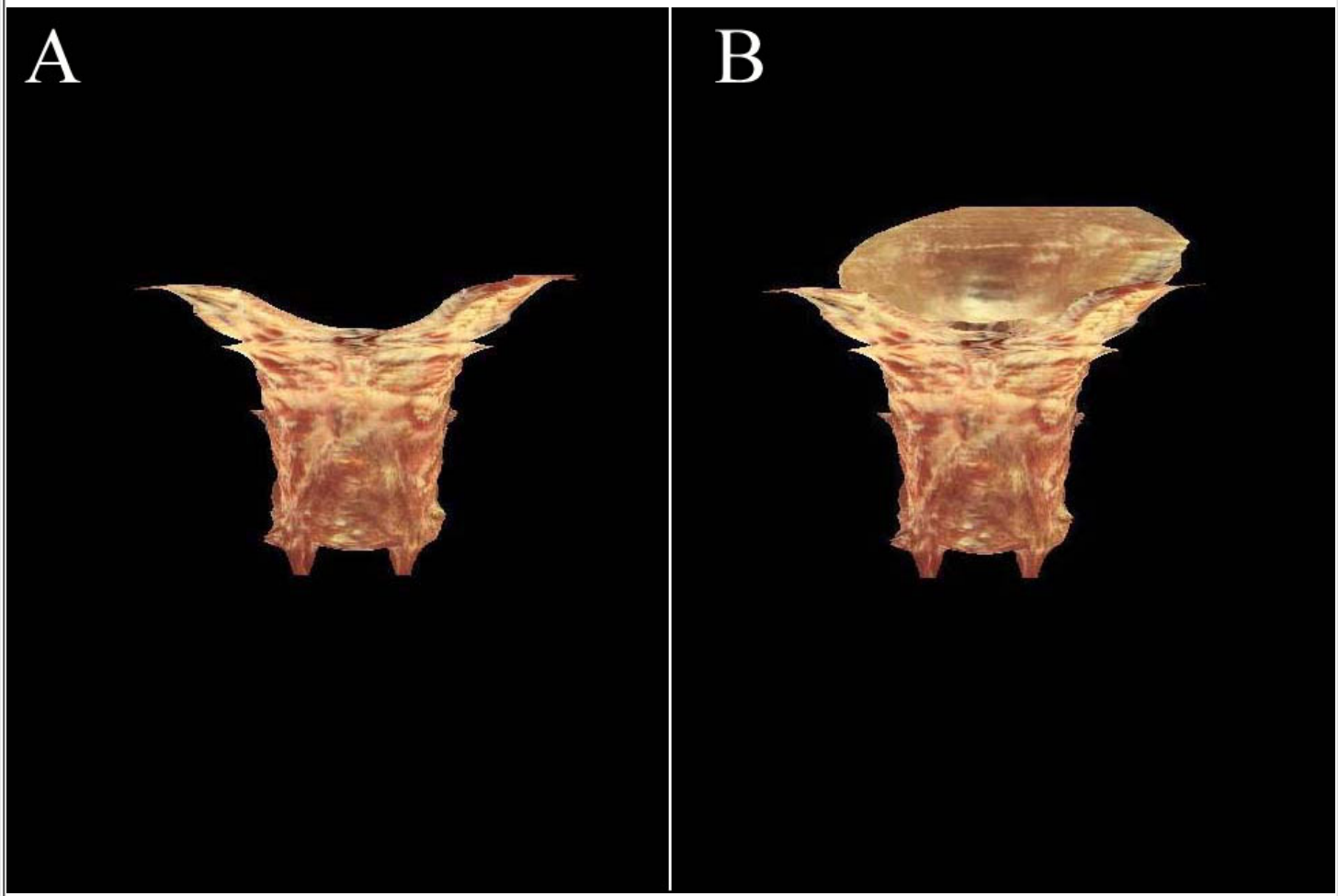


Figure 1. A) Posterior view of the reconstruction of the levator ani muscle showing its funnel shape. B) The levator ani muscle shown with the urinary bladder and prostate. [return to text]

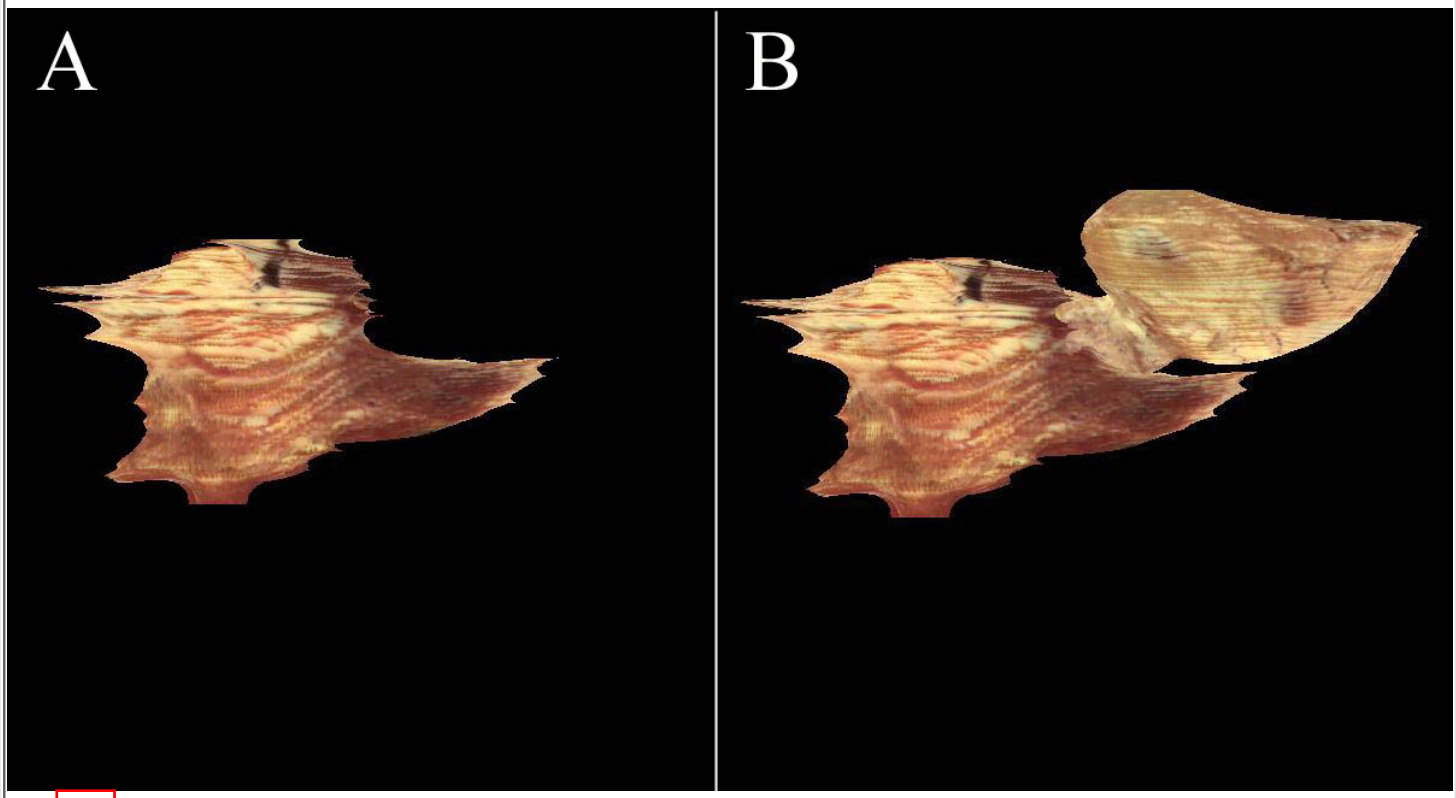


Figure 2. A) Lateral view of the reconstructed levator ani muscle. B) The levator ani muscle as in A with the urinary bladder and prostate. The levator ani is convex anteriorly and posteriorlyand B. [return to text]

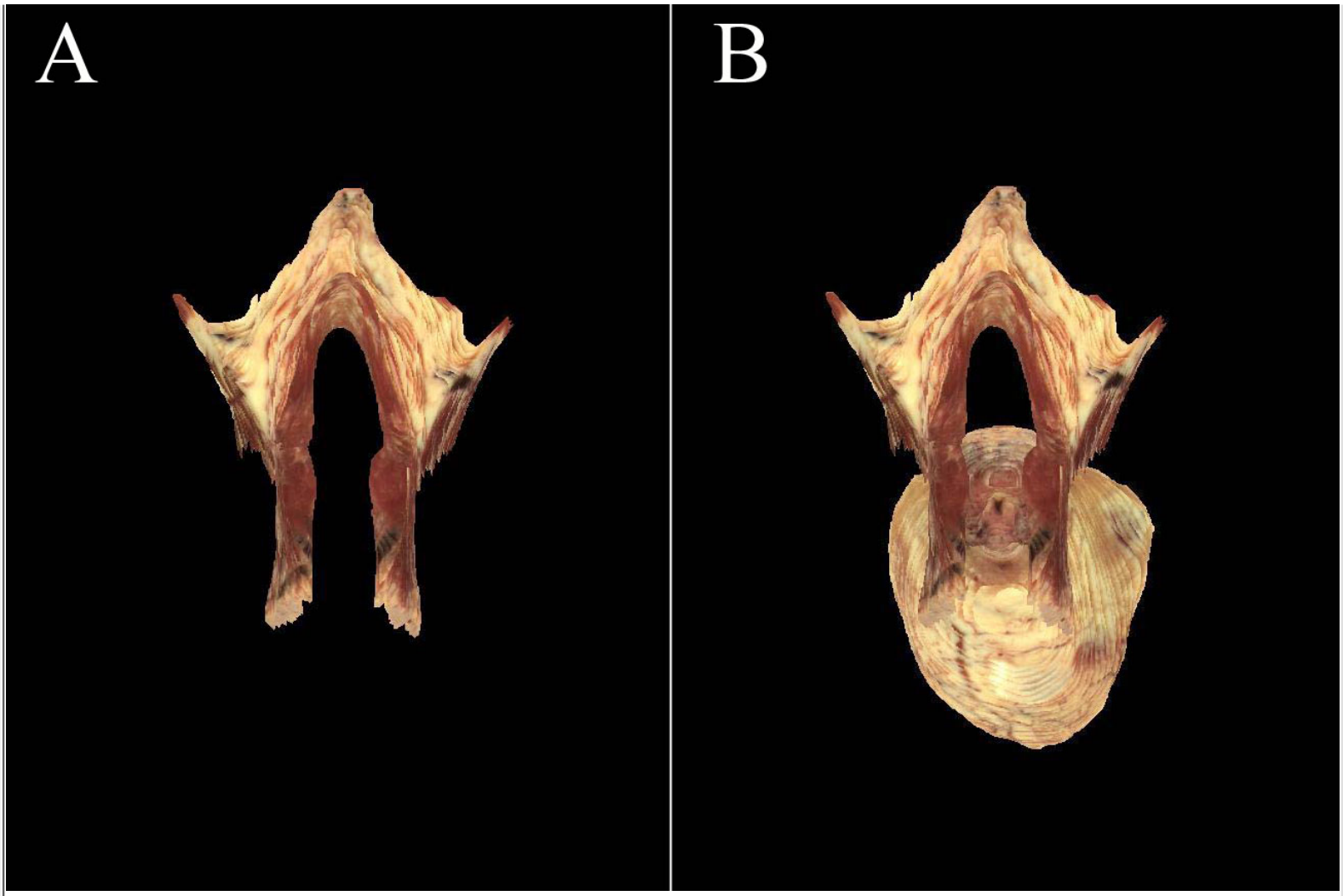


Figure 3. A) The levator ani muscle shown from below in isolation to demonstrate its funnel-shape. B) The same as in A with the bladder and prostate added in their correct anatomical relationships. [return to text]

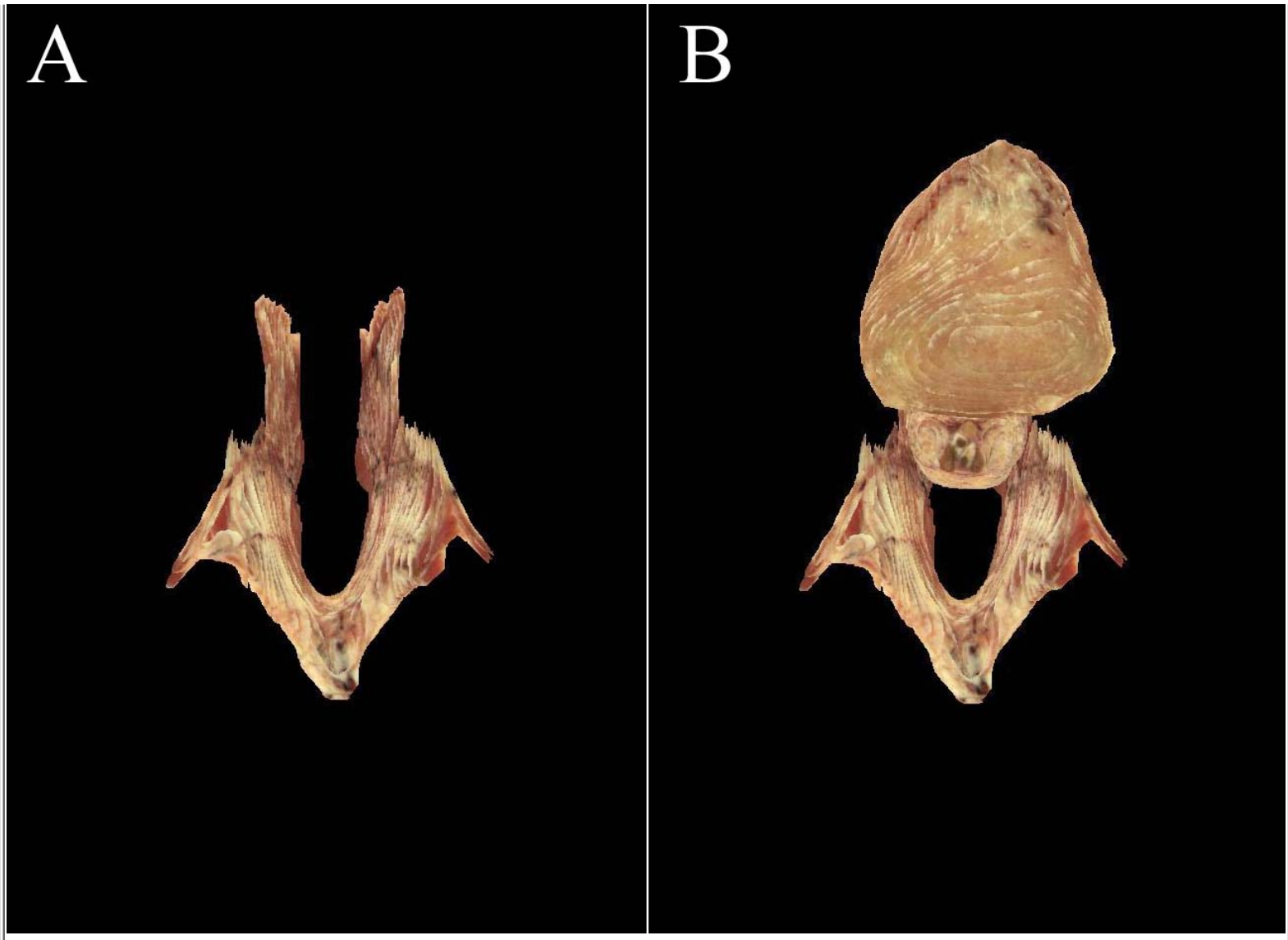


Figure 4. A) A superior view of the levator ani muscles. B) The same as in A with the prostate and urinary bladder shown in their correct anatomical positions. [return to text]

Figure 5. Posterior view of obturator internus muscles. [return to text]

Figure 6. Posterior view of obturator internus and levator ani muscles. [return to text]

Figure 7. A perineal view (inferior view) of the pelvic bones. [return to text]

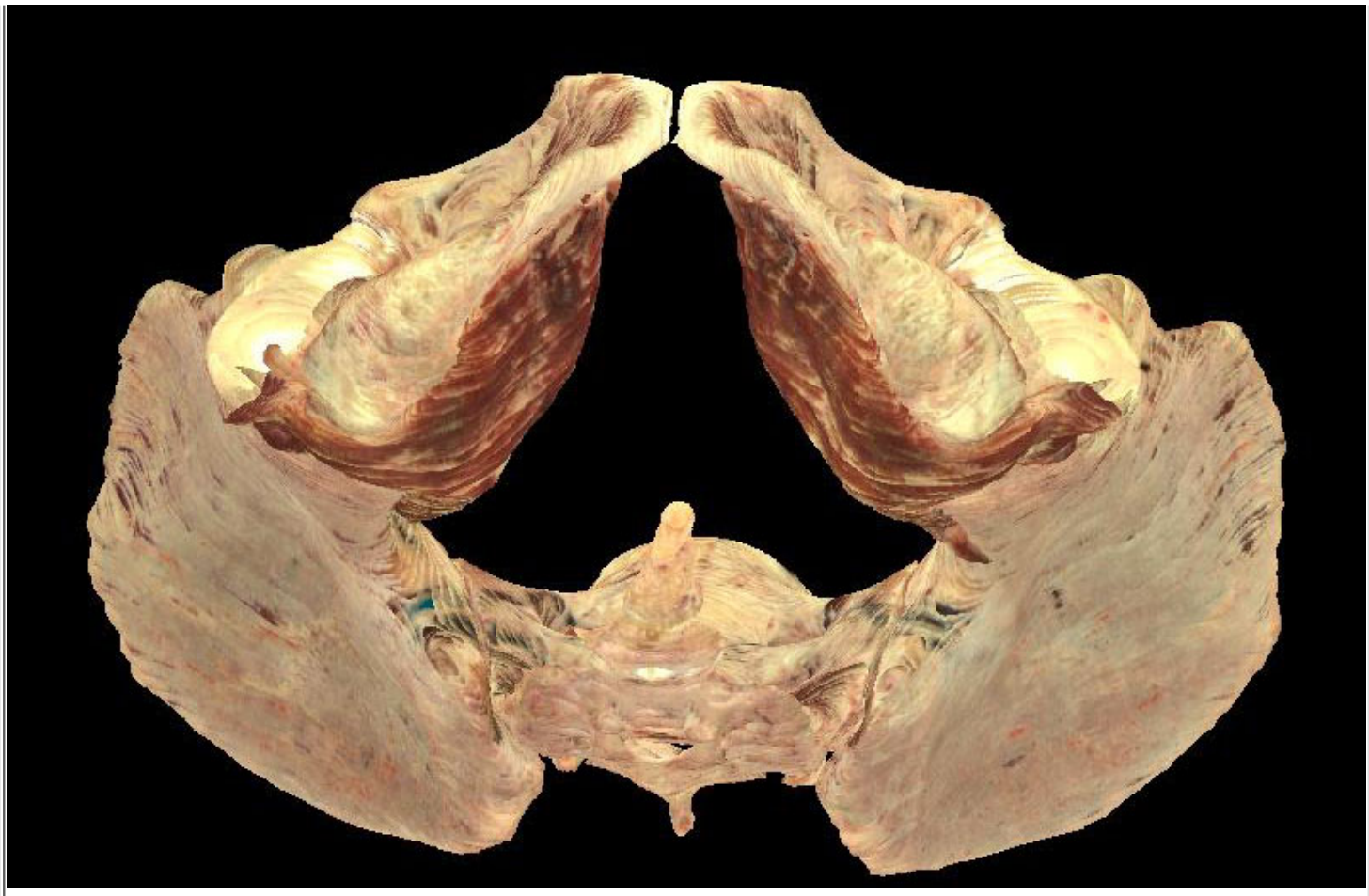


Figure 8. The pelvic bones as in Fig.7 with the obturator internus muscles added. [return to text]

Figure 9. The pelvic bones and obturator internus muscles as in Fig. 8 with the the pelvic diaphragm (levator ani and coccygeus muscles) added. [return to text]

Figure 10. The pelvic bones, obturator internus muscles and pelvic diaphragm as in Fig..9 with the deep transverse perenei muscles added. [return to text]

Figure 11. The pelvic bones, obturator internus muscles, pelvic diaphragm and deep transverse perenei muscles as in Fig.10 with the erectile tissues added.
[return to text]

Figure 12. The pelvic bones, obturator internus muscles, pelvic diaphragm, deep transverse perenei muscles and erectile tissue as in Fig. 11 with the ischiocavernosus muscles added. [return to text]

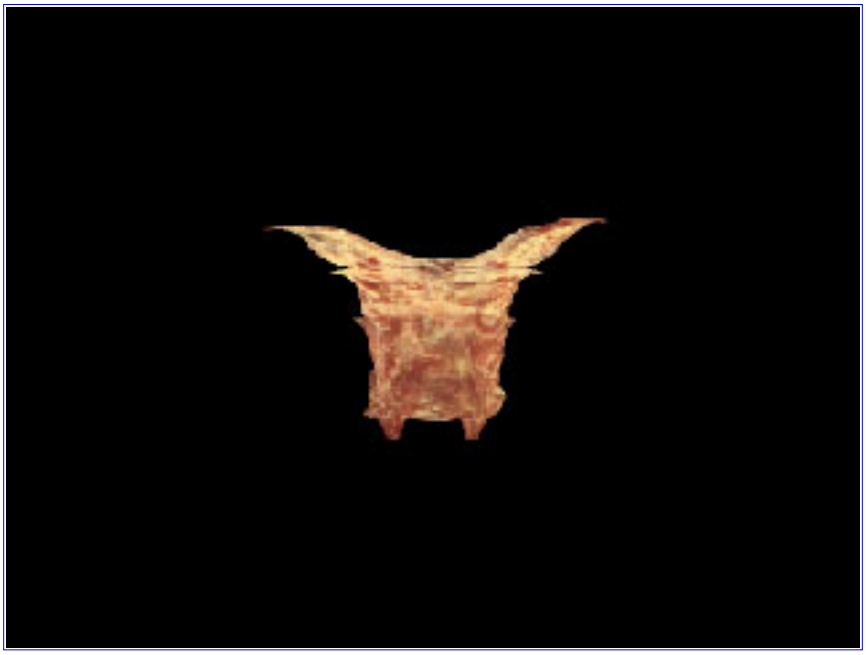
Figure 13. The pelvic bones, obturator internus muscles, pelvic diaphragm, deep transverse perenei muscles, erectile tissue and ischiocavernosus muscles as in Fig. 12 with the bulbospongiosus muscles added. [return to text]

Figure 14. The pelvic bones, obturator internus muscles, pelvic diaphragm, deep transverse perenei muscles, erectile tissue, ischiocavernosus muscles and bulbospongiosus muscles as in Fig. 13 with the superficial transverse perenei muscles added. [return to text]

Figure 15. The urinary bladder shown in its relation to the prostate and male external genitalia. [return to text]

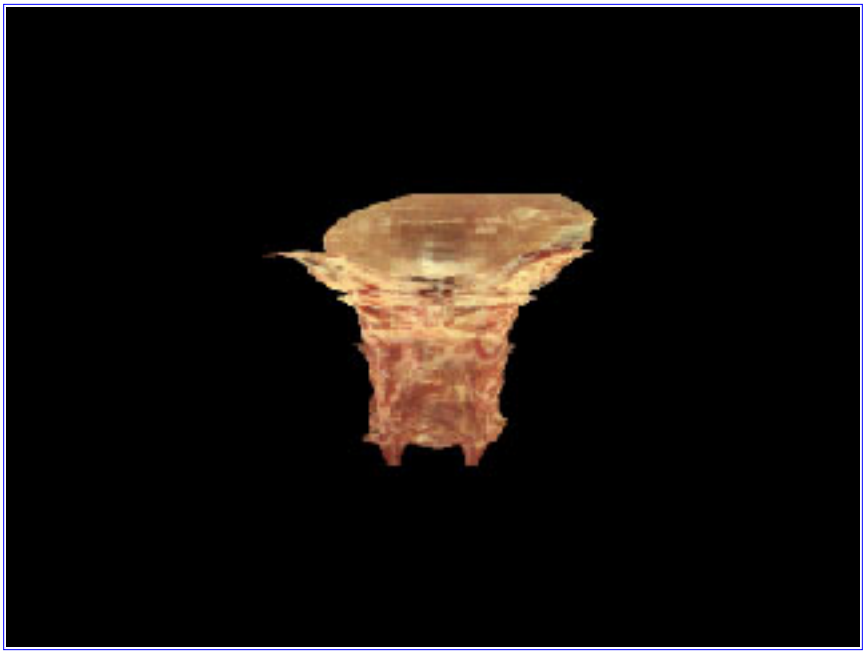
3D Visualization of the Male Pelvis and Perineum:

Movie Index



Click on image to view movie.

Movie 1. The levator ani muscles in isolation. The muscles' "funnel" shape is more apparent from this 3D representation than from standard 2D views.



Click on image to view movie.

Movie 2. The levator ani muscles shown with the urinary baldder and prostate gland to show the close apposition of these muscles to the prosate.

Click on image to view movie.

Movie 3. The pelvic bones and obturator internus muscles which form the lateral walls of the pelvis and the origin for the levator ani (see Movie 4) to view this relationship in 3D.

Click on image to view movie.

Movie 4. The Levator ani muscles are now added to the structures in movie 3 so that the relationship between the levator ani and the pelvic walls are more easily discerned.

Click on image to view movie.

Movie 5. A posterior view of the pelvic bones with the pelvic muscles added in the following sequence:

1. Obturator internus muscles
2. Levator ani muscles
3. Coccygeus muscles
4. Piriformis muscles

Click on image to view movie.

Movie 6. An inferior view of the pelvic bones with perineal structures added in the following order:

1. Obturator internus muscles
2. Levator ani muscles
3. Coccygeus muscles
4. Deep transverse perineal muscles
5. Corpora cavernosa
6. Corpus spongiosum (minus bulb of penis)
7. Ischiocavernosus muscles
8. Bulbospongiosus muscles
9. Superficial transverse perineal muscles

Click on image to view movie.

Movie 7. The male urogenital system to show the relationship of the urinary bladder to other structures of the region.

Click on image to view movie.

Movie 8. The urinary bladder (with prostate and a portion of the ureters and urethra) showing its relationship to the pelvic bones.

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